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Comparative Analysis of Fresnel Lens Performance in Malaysia and Nigeria

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Abstract
Fresnel lens concentrator made from (PMMA poly methyl metha crylate) was chosen for it`s durability, efficiency and light weight as a solar thermal concentrator for an outdoor experiments in two different tropical climates for comparison. The data collected (Stagnation temperature, ambient temperature and solar irradiance) was used to determine and compare the Figure of merit and maximum thermal conversion efficiency for the lens at no load in both countries. The results indicate that the Fresnel lens may likely perform better in Nigeria dry (tropical climate) than in Malaysia wet (tropical climate). This could be utilized to develop sustainable energy devices for cooking and other thermal energy generation to reduce health risk and energy cost.
Keywords: Fresnel lens, Efficiency, Figure of Merit, Tropical Climate, stagnation Temperature

1. Introduction

The introduction of chemicals that can threat the health of human being, animals, and plants as well as damage the environment is referred to as air pollution, indoor and outdoor activities, such as cooking, smoking, car emissions and other industrial outputs into the atmosphere plays great role in creating these pollution [1].

In its 2014 report, the World Health organization (WHO), reported that 4.3 million deaths were attributed to household air pollution (HAP) in 2012, almost all in low and middle income (LMI) countries mostly as a result of daily cooking activities using fuel wood with South East Asia taking the highest toll [2].

The rapid growth in global energy demand attributed to rising population and old method of cooking using fuel wood and coal is unsustainable due to greenhouse emissions [3], about 88 % of this demand is met presently by fossil fuels [4].

To overcome the detrimental effect of fuelwood used for cooking and fossil fuell to socio-economic life of the people [5]. A research is set out to compare and determine the performance of Fresnel lens for thermal (cooking, process heating, space heating) and subsequently electricity generation in two different tropical (wet & dry) countries with the aim of possibly minimizing indoor and ambient air pollution considering the fact that potentials of solar radiation and its components varies with location and can easily affect the performance of solar concentrator systems [6].

Malaysia and Nigeria were chosen from different tropical climates in Asia and Africa respectively for the research, however Malaysian weather is highly associated with cloudy and humid condition, while the Northern part of Nigeria is dry, clear and sometimes hazy with very little visibility, the experiment was carried out under these conditions to establish the performance of the lens under investigation.

Based on the experimental data reported here for the Fresnel lens, sunlight to thermal energy conversion efficiency η, figure of merit F were determined to compare the performance of the lens for possible adoption into small standalone system for both cooking and electricity generation [5].

Fresnel lens is a flat optical component made from (PMMA poly methyl metha crylate)with its surface made up of many small concentric grooves with each groove behaves like an individual prism, it is expected to be the most desirable candidates for thermal and electricity generation in the near future, when compared with the existing large CSP (parabolic trough, tower, linear reflectors and chimney) systems due to it`s favourable material properties including; low weight, mechanical strength, temperature resistance, and inexpensive manufacturing among other factors [7].

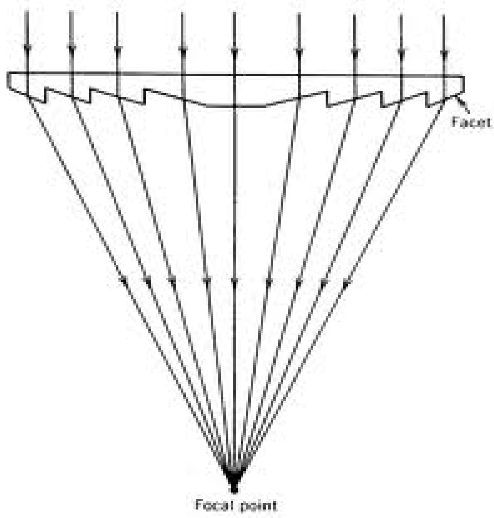

Fig. 1 Schematic Diagrams of Fresnel Lens.

1.1 Tropical Rain Forest Climate (Malaysia)

Malaysia is located at 2^0 30' N, 112^0 30' E latitude just above the equator with uniformly high temperatures about 32°C-33°C around Kula Lumpur where the experiment was carried out, with high humidity of about 70%-80%, average wind speed of about 2m/s and it used to be wet throughout the year. Malaysia receives an average 6 hours of sunshine per day [8]. The annual average daily solar irradiation for Malaysia is 4.21–5.56 $kWhm^{-2}$ [9].

However one of the major constraints for solar thermal generation in Malaysia is persistent appearance of clouds almost year round which causes scattering [11].

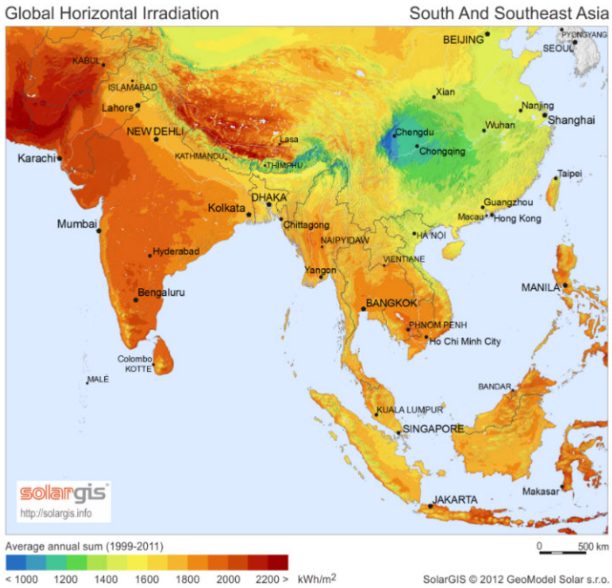

Fig. 2 Yearly Global Horizontal Irradiationfor South East Asia with Malaysia [10].

1.2 Tropical Continental Climate (Nigeria)

Nigeria is located at 10^0 00' N, 8^0 00' E above the equator only has two seasons, the wet (short) and longer dry seasons. The experiment was carried out in the Northern part of the country (Katsina) which is a tropical dry Climate with an average humidity of 20% and average temperatures of 44°C, dusty (hazy) dry air mass is experienced with very low visibility and temperatures going down to about 15-17°C, average wind speed is about 4-5m/s with an average 8-9 hours of sunshine [12]. The annual average daily solar irradiations for Nigeria have a magnitude of 5.5-6.6 $kWhm^{-2}$.

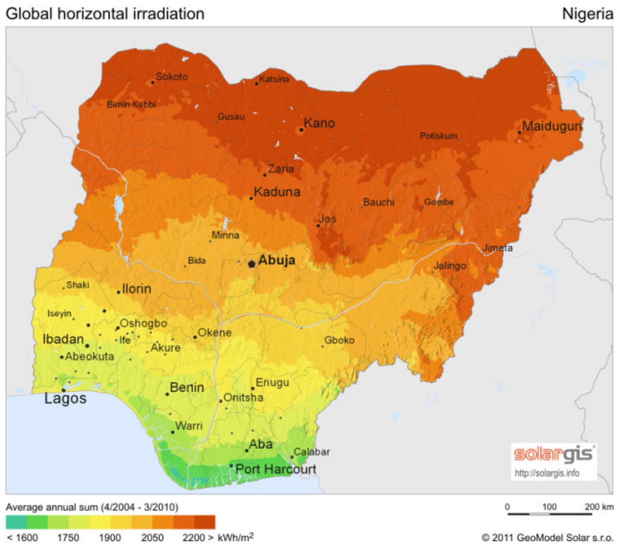

Fig. 3 Yearly global horizontal irradiationin Nigeria [10].

In Nigeria the major climatic problem for solar thermal generation is dusty (hazy) dry air mass is experienced with very low visibility for almost 3 month.

2 Methodologies

An outdoor experiment was setup in Malaysia and Nigeria to establish the performance of the lens under investigation by measuring stagnation temperature, solar irradiance and ambient temperature for simple thermodynamic analysis.

The system was setup as seen in figure 8, a Lab VIEW based automated data acquisition computer program was used to acquire the values of stagnation temperature using type K thermocouple and irradiance data using apogee silicon cell pyranometer (SP110) calibrated in July 2012 by National Renewable Energy Laboratory (NREL) respectively, averaging the entire readings at 5minute interval at an average wind speed of 2m/s in Malaysia and 4m/s in Nigeria respectively for several days.

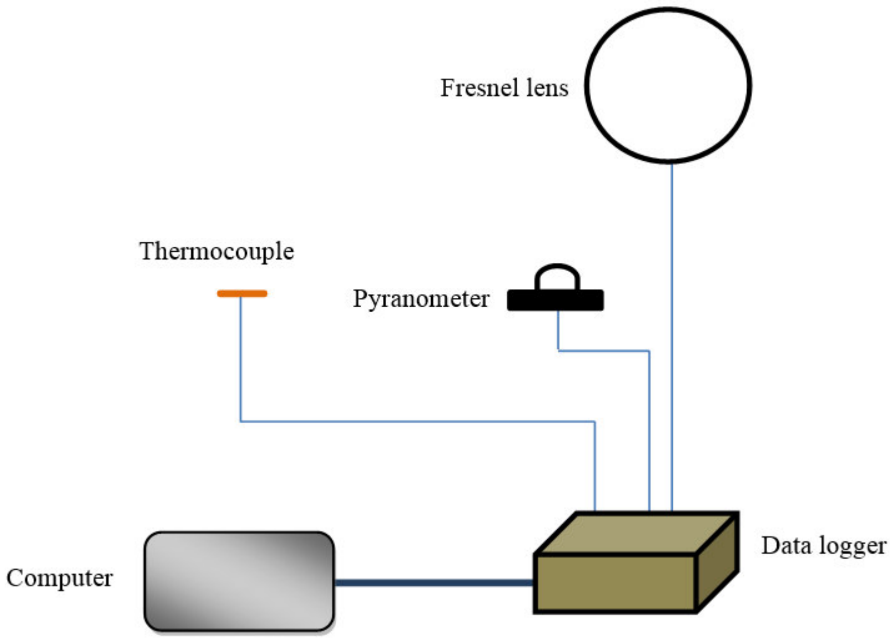

Fig. 4 Schematic for Experimental setup

3 Results and Discussion

Experimental data and average calculated parameters for 50cm Spot Fresnel lens were determined in Malaysia and Nigeria as shown in the graphs below.

3.1 Stagnation Temperature

The highest stagnation temperature obtained in Malaysia at around 1000W/m^2 irradiance was at ~700°C while Nigeria at about 700W/m^2 the temperature goes up to ~1200°C as shown in figures 5 and 6 respectively.

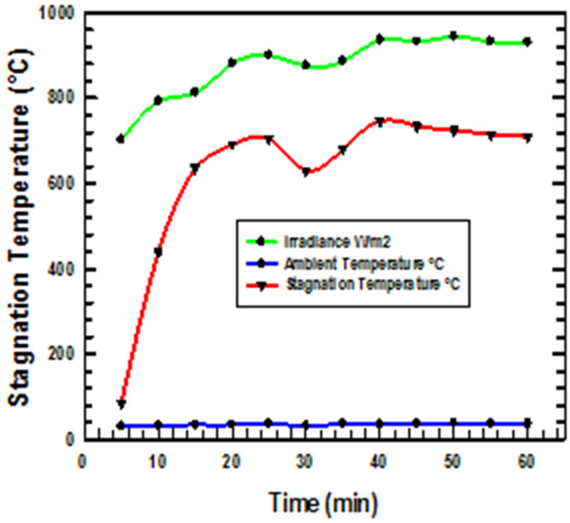

Fig. 5 Stagnation temperature, ambient temperature and solar irradiation as a function of time for 50cm spot Fresnel lens in Malaysia

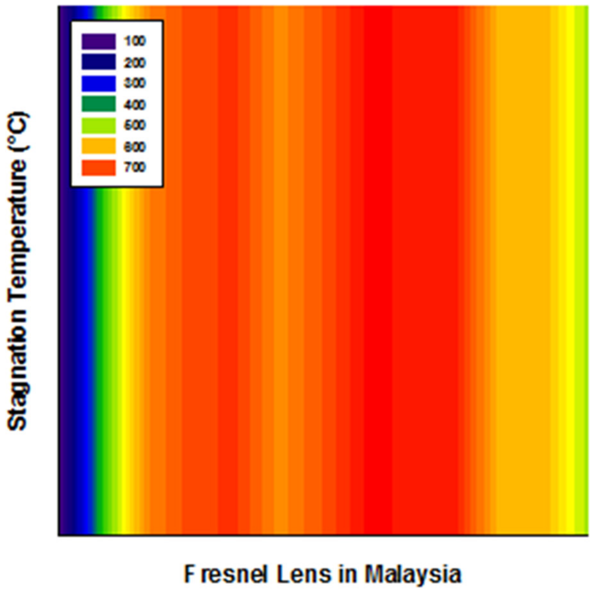

Fig. 7 Stagnation temperature contour graph for 50cm spot Fresnel lens in Malaysia

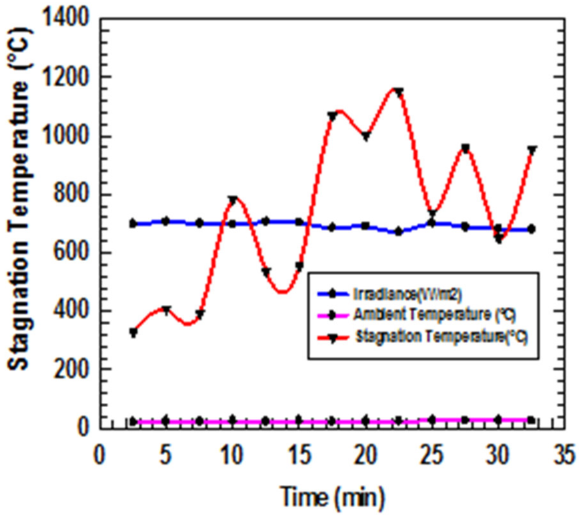

Fig. 6 Stagnation temperature, ambient temperature and solar irradiation as a function of time for 50cm spot Fresnel lens in Nigeria

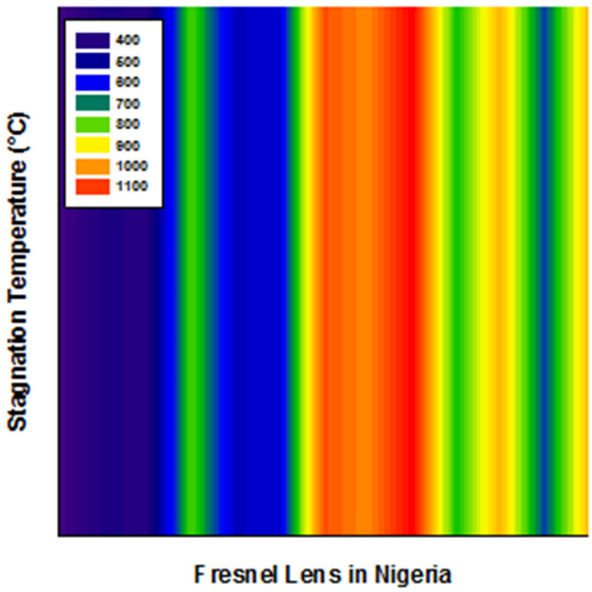

Fig 8 Stagnation temperature contour graph for 50cm spot Fresnel lens in Nigeria

3.2 Conversion Efficiency

The Maximum conversion efficiency for the thermal system were determined and compared as shown in the graph.

$E = 1 - T_{\infty}/T_P$ (1)

where E, is the efficiency of the concentrator, T_{∞} ambient temperature and T_P plate temperature [11].

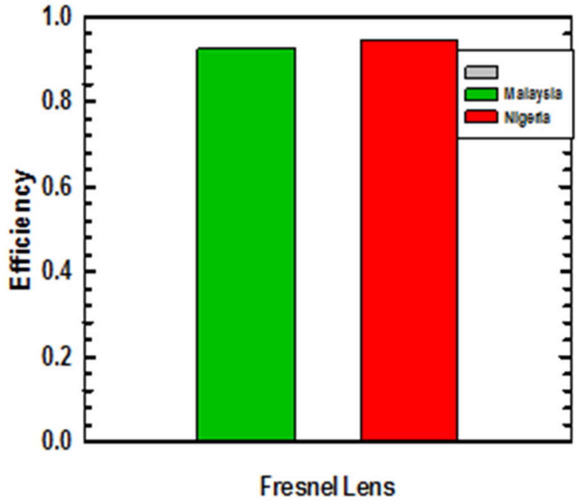

Fig. 9 Efficiency as a function of Fresnel lens in Malaysia and Nigeria

The efficiency of a collector is an indication of its thermal performance, and it is defined as the ratio of the useful energy delivered by the collector to the solar flux incident at the collector aperture.

3.3 Figure of merit

This is a quantity used to characterize the performance of a device in order to determine their relative utility for an application for the two cases were also plotted and compared, it is however the ratio of optical efficiency to the heat loss factor by the absorbing plate and is a measure of the differential temperature gained by the absorbing plate at a particular level of solar insolation, it is dependent on climatic condition and the first figure of merit F_1 determined by stagnation test at no load conditions is expressed mathematically.

$$F' = \eta_o/U_L = (T_P - T_\infty)/I_s \qquad (2)$$

Where η_o is the optical efficiency, U_L heat lost factor, T_P the plate temperature, T_∞ -ambient temperature and I_s solar insolation [12].

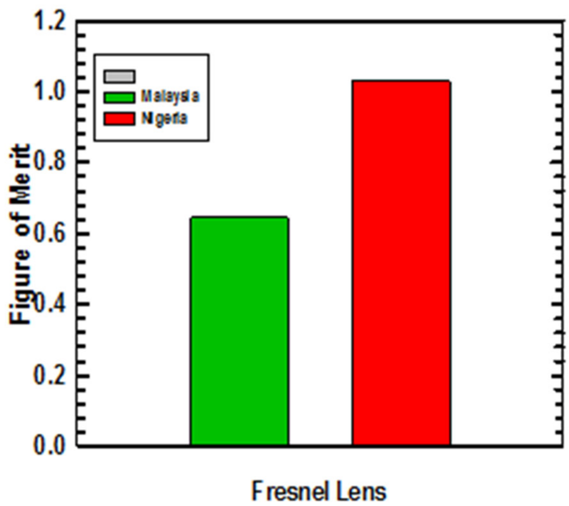

Fig. 10 Figure of Merit as a function of Fresnel Lens in Malaysia and Nigeria.

The efficiencies for the lens under investigation were found to be **0.923** in Malaysia and **0.945** in Nigeria, while the figure of merit was **0.644** in Malaysia and **1.029** in Nigeria respectively.

4 Conclusion

Weather pattern influences collector performance [13], the stagnation temperature is very much affected by wind blowing across the un insulated receiver, though irradiation is virtually stable as can be seen clearly from the graph for Nigeria, while in Malaysia the irradiation fluctuates due persistent cloudy condition and the stagnation temperature follow the cloud pattern as can be seen in the graphs also.

Thus the tropical climatic condition of Nigeria based on the Fresnel Lens investigated, was determine to be the most desirable condition for thermal and electricity generation most especially with well insulated receiver and other heat transfer parts, when compared to Malaysia however Fresnel lens could be used in the design of solar energy applications and other related mechanisms [5],a good example of these systems includes a sustainable solar cooker that can reduce difficulty in cooking, save the environment from excessive CO_2 and related pollutants as well as reduce health risk and cost of cooking, another system is a modular micro grid electricity generation system.

4.1 Future Work

Based on several experiments carried out, two Fresnel lens based systems for solar cooking and electricity generation are currently under construction.

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